American Journal of Epidemiology

Vol. 157, No. 9
Printed in U.S.A.
DOI: 10.1093/aje/kwg050

Injury Risk in Men's Canada West University Football

Brent E. Hagel[1], Gordon H. Fick[2], and Willem H. Meeuwisse[3]

[1] Department of Epidemiology and Biostatistics, Faculty of Medicine, McGill University, Montreal, Quebec, Canada.
[2] Department of Community Health Sciences, Faculty of Medicine, University of Calgary, Calgary, Alberta, Canada.
[3] University of Calgary Sport Medicine Centre, Faculty of Kinesiology, University of Calgary, Calgary, Alberta, Canada.

Received for publication December 28, 2001; accepted for publication November 5, 2002.

Injury and participation information was collected over 5 years (1993–1997) on varsity men's football players in the Canada West Universities Athletic Association. The locations of acute time-loss injuries or neurologic injures were coded as head and neck, upper extremity (shoulder to hand), or lower extremity (hip to foot). Poisson regression-based generalized estimating equations were used to estimate rate ratios and 95% confidence intervals. Injury rates were higher during games as compared with practice periods (for the head and neck, rate ratio (RR) = 9.75 (95% confidence interval (CI): 7.50, 12.67); for upper extremities, RR = 5.76 (95% CI: 4.46, 7.45); and for lower extremities, RR = 7.06 (95% CI: 6.03, 8.25)). In dry-field game situations, head and neck injury rates were 1.59 times higher on artificial turf than on natural grass (95% CI: 1.04, 2.42). Lower extremity game injury rates were higher on artificial turf than on natural grass under both dry (RR = 1.83, 95% CI: 1.35, 2.48) and wet (RR = 2.31, 95% CI: 1.18, 4.52) field conditions. Injury rates increased with every additional year of participation. Past injury increased the rate of subsequent injury. The effect of an artificial field surface may be related to infrequent use. Risk factors for injury included participation in a game, playing on artificial turf, being a veteran player, and having a past injury.

athletic injuries; cohort studies; football

Abbreviations: CI, confidence interval; GEE, generalized estimating equations; RR, rate ratio.

Canadian football is a contact sport, with intentional player collisions and tackling being an integral part of the game. On a rectangular field 110 yards (101 m) long and 65 yards (59 m) wide, 12 members of the offensive team (the team possessing the ball) line up facing an equal number of defensive players prior to the beginning of each play. All players wear helmets with facial protection, shoulder pads, and hip-thigh protection. The leader of the offensive team, or "quarterback," receives the ball from one of his offensive linemen (the "center") after a specified count to begin a particular play (i.e., a "down"). The quarterback may hand off or pass the ball to an eligible receiver or run with the ball himself in order to progress downfield into the defensive team's territory. Ultimately the offensive team must move the ball into the zone at the end of the field or kick the ball through the upright goal posts to score. A detailed description of the rules of Canadian football is available online at www.cfl.ca/CFLRulebook/.

Because of the size and speed of the players engaged in this type of football, extreme collision forces can produce severe, even life-threatening injuries. Many factors have been implicated as contributing to the occurrence of football injuries. Factors such as the type of field surface (1–3), field conditions (4), session type (2, 5–12), and history of injury (4, 7, 13–15) have all been studied to determine which affects injury risk, either independently or in combination with others. However, there are shortcomings identifiable with past investigations of football injury risk, primarily concerning the assessment of athlete participation (16–18). Therefore, we conducted an investigation among members of the Canada West Universities Athletic Association to determine which risk factors best predict injury incidence and severity in specific body regions, either alone or in combination, for intercollegiate football players. Once identified, risk factors can be eliminated or modified for injury prevention.

Correspondence to Dr. Willem H. Meeuwisse, University of Calgary Sport Medicine Centre, Faculty of Kinesiology, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada (e-mail: meeuwiss@ucalgary.ca).

TABLE 1. Overall rates of acute injury among football players in the Canada West Universities Athletic Association, by body region and type of playing session (game vs. practice), 1993–1997

Body region and type of session	No. of injuries	No. of exposures	Unadjusted rate of injury*	Unadjusted rate ratio	Adjusted† rate ratio	95% confidence interval
Head and neck						
Practice‡	142	89,556.0	1.59			
Game	154	10,224.5	15.06	9.50	9.75	7.50, 12.67
Upper extremity						
Practice‡	176	89,556.0	1.97			
Game	115	10,224.5	11.25	5.72	5.76	4.46, 7.45
Lower extremity						
Practice‡	384	89,556.0	4.29			
Game	305	10,224.5	29.83	6.96	7.06	6.03, 8.25

* Number of injuries per 1,000 athlete exposures.

† Poisson regression model using generalized estimating equations to account for within-subject correlation.

‡ Reference category.

MATERIALS AND METHODS

This prospective cohort study utilized three data collection instruments: a preseason medical form to document history of injury, a daily participation log for every athlete, and an injury reporting form. Specific aspects of the overall data collection process, including the data collection instruments used, have been described previously (16–19). Acute injuries are the focus of this report and were defined as 1) any injury resulting in one or more complete or partial sessions of time loss and 2) any concussion or transient neck neurologic injury.

If an injury occurred at the end of the season or occurred in-season but caused the player to miss playing time up to the end of the season, time loss was based on the greater of the measured time loss (from the athlete participation log) or the therapist/physician assessment of time loss (from the injury report form).

The rate of injury to a particular body region was used as the outcome or dependent variable. This was done to determine the specificity of particular risk factors in relation to the part of the body affected. The three primary regions of injury analyzed were the head and neck (injuries to the head or neck, concussions, and neck neurologic injuries), the upper extremities (shoulder to hand), and the lower extremities (hip to foot). Thoracic spine-chest and lumbar spine-pelvis injuries were also examined in the indicated analyses.

Predictor variables included type of playing session (game vs. practice), field type (artificial turf vs. natural turf), field conditions (wet vs. dry), year of varsity sport participation (assessed both as a continuous variable and as a categorical variable where indicated), university (British Columbia, Alberta, Calgary, Manitoba, or Saskatchewan), and history of injury (present vs. absent). Any injury to a particular body region noted on the preseason medical form was considered to constitute a positive history for that region in the analysis. However, an injury that occurred during the season was only categorized as a past injury (from that point in the season onward) if the injury resulted in partial or complete time loss.

We estimated unadjusted incidence density ratios by specifying the number of injuries per 1,000 athlete exposures for each of the conditions being compared. However, because outcomes were not all independent—that is, because many players sustained multiple injuries—Poisson regression models were fitted using generalized estimating equations (GEE). The GEE approach accounts for correlation in individuals with multiple injuries, which is the case in these data. The beta coefficients from this model estimate the injury incidence density ratio (i.e., rate ratio) accounting for the nonindependence of the data (20). These ratios were compared with the unadjusted rate ratios obtained from simply expressing the number of injuries per 1,000 athlete exposures under the presence versus absence of the risk factor of interest, an approach that does not take into account correlated outcomes. This analysis was completed using Stata statistical software (21).

We conducted a sensitivity analysis of the potential for bias related to differential (across the exposure contrast) underreporting of injury. This analysis proceeded according to the method described by Rothman and Greenland (22) for person-time follow-up data with the tenable assumptions of no false-positive injury reporting (i.e., perfect specificity) and negligible alteration of person-time.

RESULTS

In these data, there was evidence that participation in games increased the rates of head and neck, upper extremity, and lower extremity injury (table 1). The rate ratio appeared to be greatest for head and neck injuries.

There were 27 artificial turf games played at two Canada West locations on AstroTurf® brand synthetic turf (Southwest Recreational Industries, Leander, Texas), while nine additional artificial turf games were played between one Canada West team and one non-Canada West team. The type of artificial turf could not be determined for only one of

TABLE 2. Rates of acute injury among football players in the Canada West Universities Athletic Association, by type of playing surface (artificial turf vs. natural grass), 1993–1997

Body region and type of surface	No. of injuries	No. of exposures	Unadjusted rate of injury*	Unadjusted rate ratio	Adjusted† rate ratio	95% confidence interval
Head and neck						
Natural field‡	231	87,594.0	2.64			
Artificial turf§	59	10,112.0	5.83	2.21	2.11	1.52, 2.93
Upper extremity						
Natural field‡	239	87,594.0	2.73			
Artificial turf§	46	10,112.0	4.55	1.67	1.62	1.17, 2.24
Lower extremity						
Natural field‡	540	87,594.0	6.16			
Artificial turf§	138	10,112.0	13.65	2.21	2.15	1.76, 2.63

* Number of injuries per 1,000 athlete exposures.

† Poisson regression model using generalized estimating equations to account for within-subject correlation.

‡ Reference category.

§ There were 27 games between two teams in the Canada West Universities Athletic Association (CWUAA) and nine games between CWUAA teams and non-CWUAA teams, with all but one of those nine determined to have been played on an AstroTurf synthetic field.

those nine contests; the remaining eight games were played on AstroTurf. Thus, the vast majority of artificial turf exposures were on AstroTurf. A team from one institution played all of their home games over the 5-year period on AstroTurf. An additional team began playing home games on AstroTurf for the 1997 season only. Table 2 demonstrates evidence of a greater rate of injury associated with participation on AstroTurf versus natural grass for head and neck, upper extremity, and lower extremity injuries.

A separate stratified game analysis was carried out to determine effects of field type. Results are presented in table 3. The analysis was restricted to games because of the lack of player participation on artificial turf during practices and because of the strong evidence for higher injury incidence rates during games. Comparisons were adjusted for university, since there was speculation that the one team with the most participation on artificial turf (the University of Calgary team) also had a more aggressive style of play. There was some evidence to suggest that head and neck injury rates were higher on AstroTurf, but only under dry game conditions after adjustment for university. Upper extremity injury rates appeared to be relatively unaffected by field type and field conditions during games. There was evidence to suggest higher rates of lower extremity injury during game participation on AstroTurf as compared with natural grass after adjustment for university. Furthermore, the risk may have been greater for wet as compared with dry field conditions, although the confidence limits demonstrated substantial overlap.

We conducted an additional analysis comparing rates of injury on AstroTurf and natural grass by team, because the University of Calgary team, whose home venue always had an AstroTurf surface, had much more exposure to this surface than other teams in the Canada West Universities Athletic Association. This analysis was restricted to the 1993–1996 football seasons, since an additional team began playing all of their home games on an AstroTurf field in 1997. There was no evidence to suggest that University of Calgary players had an increased rate of either head and neck (rate ratio (RR) = 0.76, 95 percent confidence interval (CI): 0.40, 1.43) or lower extremity (RR = 0.84, 95 percent CI: 0.51, 1.38) injuries when playing on AstroTurf as compared with a natural field. However, there was evidence to suggest that head and neck (RR = 2.36, 95 percent CI: 1.40, 3.98) and lower extremity (RR = 2.78, 95 percent CI: 1.99, 3.89) injury rates were greater on AstroTurf than on grass for all other teams combined. There was no evidence to suggest that the rate of upper extremity injury changed with field type for any of the teams under investigation.

Table 4 suggested an increasing risk of head and neck and lower extremity injuries with each additional year of participation in varsity football when data were controlled for past injury. The Poisson regression equation predicted that the rate in any given year was 19 percent (95 percent CI: 9, 31) higher than the rate in the previous year for the head and neck. Lower extremity injury rates were estimated to increase 15 percent (95 percent CI: 9, 23) per additional year of participation. Upper extremity injury rates were estimated to increase 10 percent (95 percent CI: 1, 21) per additional year of participation, although the confidence limits crossed the null value.

Table 5 demonstrates that there was evidence to suggest a greater rate of neck injuries, brachial plexus or "burner" injuries (i.e., a stretch injury to the nerves of the brachial plexus), and concussions when an individual had a history of injury, after results were controlled for year of varsity sport participation. There was no evidence to suggest a greater rate of subsequent head injury (excluding concussions) given a prior head injury, after data were controlled for year of varsity sport. There was evidence to suggest that the rate of upper extremity, trunk, and lower extremity injuries increased given a history of injury, after control for year of varsity sport. The rate of lumbar spine/pelvis injuries was estimated to be higher among those athletes with a history of

TABLE 3. Rates of acute injury in game situations among football players in the Canada West Universities Athletic Association, by body region and type of playing surface (artificial turf vs. natural grass), under both wet and dry field conditions, 1993–1997

Body region, field conditions, and type of surface	No. of injuries	No. of exposures	Unadjusted rate of injury*	Unadjusted rate ratio	Adjusted† rate ratio	95% confidence interval
Head and neck						
Dry game						
Natural field‡	71	5,508.0	12.89			
Artificial turf§	45	1,806.5	24.91	1.93	1.59	1.04, 2.42
Wet game						
Natural field‡	22	2,156.0	10.20			
Artificial turf§	4	241.5	16.56	1.62	0.80	0.29, 2.21
Upper extremity						
Dry game						
Natural field‡	58	5,508.0	10.53			
Artificial turf§	28	1,806.5	15.50	1.47	1.14	0.69, 1.89
Wet game						
Natural field‡	17	2,156.0	7.88			
Artificial turf§	3	241.5	12.42	1.58	1.41	0.36, 5.60
Lower extremity						
Dry game						
Natural field‡	132	5,508.0	23.97			
Artificial turf§	90	1,806.5	49.82	2.08	1.83	1.35, 2.48
Wet game						
Natural field‡	45	2,156.0	20.87			
Artificial turf§	16	241.5	66.25	3.17	2.31	1.18, 4.52

* Number of injuries per 1,000 athlete exposures.

† Poisson regression model using generalized estimating equations to account for within-subject correlation. Results were controlled/adjusted for university.

‡ Reference category.

§ There were 27 games between two teams in the Canada West Universities Athletic Association (CWUAA) and nine games between CWUAA teams and non-CWUAA teams, with all but one of those nine determined to have been played on an AstroTurf synthetic field.

injury to this region (RR = 1.47), although the confidence interval for the rate ratio ranged from 0.88 to 2.47.

When these relations were evaluated according to body part, the point estimates of the incidence rate ratios were higher than those presented in table 5 for all upper extremity injuries combined. Specifically, GEE Poisson regression rate ratio estimates, controlled for year of varsity sport, ranged from 2.23 (95 percent CI: 0.82, 6.06) for the right hand to 4.11 for the left hand (95 percent CI: 1.96, 8.63), while the estimates for the left and right shoulder were 3.0 (95 percent CI: 1.62, 5.56) and 3.71 (95 percent CI: 2.28, 6.04), respectively. Low numbers of cases for the arm, elbow, forearm, and wrist precluded sound estimates of the risk of injury given a history of injury as compared with no past injury.

For the lower extremity, the GEE Poisson regression rate ratio estimates for specific body parts ranged from 1.47 for the left foot (95 percent CI: 0.28, 7.83) to 7.21 for the right hip (95 percent CI: 2.70, 19.27), after controlling for year of varsity sport.

We conducted a sensitivity analysis to examine the effect of underreporting of neck injury among those with no past neck injury (unadjusted RR = 5.81 (table 5)), assuming that no underreporting occurred among those with a past neck injury. With 90 percent of the neck injury cases captured in the no-past-neck-injury category, the unadjusted rate ratio would change to 5.23. At 70 percent case capture in the no-past-neck-injury group, the unadjusted rate ratio would decrease to 4.1. Under the extreme condition of 50 percent case capture in the no-past-neck-injury group, the rate ratio would fall to 2.9. Neck injury capture would have to be 20 percent in the no-past-neck-injury group in order for the unadjusted rate ratio to fall to a practically and statistically insignificant value of 1.16.

DISCUSSION

This study attempted to identify risk factors for injury in Canadian intercollegiate men's football. The knowledge obtained may be useful in reducing injury rates and directing future research.

TABLE 4. Rates of acute injury in game situations among football players in the Canada West Universities Athletic Association, by year of varsity sport participation, 1993–1997

Body region and year of participation	No. of injuries	No. of exposures	Unadjusted rate of injury*	Unadjusted rate ratio	Adjusted† rate ratio	95% confidence interval
Head and neck						
Year of play						
1§	69	34,907.0	1.98			
2	68	24,015.5	2.83	1.43		
3	58	17,052.5	3.40	1.72		
4	45	12,188.0	3.69	1.87		
5	37	8,292.5	4.46	2.26		
Year of play as a continuous variable					1.19‡	1.09, 1.31
Upper extremity						
Year of play						
1§	86	34,907.0	2.46			
2	74	24,015.5	3.08	1.25		
3	51	17,052.5	2.99	1.21		
4	40	12,188.0	3.28	1.33		
5	32	8,292.5	3.86	1.57		
Year of play as a continuous variable						
Overall					1.10	1.00, 1.21
Right upper extremity					1.12‡	0.97, 1.30
Left upper extremity					0.99‡	0.86, 1.14
Lower extremity						
Year of play						
1§	195	34,907.0	5.59			
2	163	24,015.5	6.79	1.21		
3	110	17,052.5	6.45	1.15		
4	120	12,188.0	9.85	1.76		
5	78	8,292.5	9.41	1.68		
Year of play as a continuous variable						
Overall					1.15	1.09, 1.23
Right lower extremity					1.08‡	0.99, 1.17
Left lower extremity					1.18‡	1.07, 1.30

* No. of injuries per 1,000 athlete exposures.
† Poisson regression model using generalized estimating equations to account for within-subject correlation.
‡ Controlled/adjusted for history of injury.
§ Reference category.

Artificial turf versus natural turf

Although artificial turf has advantages over natural grass in terms of maintenance costs and durability (23), there has been considerable debate and research to determine whether a synthetic playing field increases athletes' risk of injury. In this study, rates of injury on AstroTurf synthetic fields were estimated to be approximately twice as high as those on natural grass for all body regions. However, when the analysis was restricted to games, only lower extremity injury rates on AstroTurf remained twice as high as those occurring on natural grass. Head and neck injury rates were elevated but not to the same extent overall, and not under wet field conditions. This suggests that athlete speed, and thus force of impact, increases on dry artificial turf because of the level field and greater shoe-surface friction.

Other investigators have found differences between artificial turf and natural fields. Specifically, AstroTurf was found to have a higher injury rate than grass fields, although Tartan Turf® (Tartan Turf Industries, Inc., Champlain, New York) had a slightly lower rate than grass (1). Furthermore, Tartan Turf had a higher associated injury rate under wet field conditions as compared with dry conditions (1). However, the investigators did not categorize injuries by body region but rather presented rates of injury overall for the different surfaces. National Collegiate Athletic Association data also indicated higher overall injury rates with artificial turf as compared with natural fields, although these data were not

TABLE 5. Rates of acute injury in game situations among football players in the Canada West Universities Athletic Association, by location of injury and history of past injury, 1993–1997

Location of injury and history of injury	No. of injuries	No. of exposures	Unadjusted rate of injury*	Unadjusted rate ratio	Adjusted† rate ratio	95% confidence interval
Head						
No past injury‡	18	76,513.0	0.24			
Past injury	3	6,379.5	0.47	2.00	1.20	0.15, 9.61
Neck						
No past injury‡	45	73,371.0	0.61			
Past injury	53	14,876.5	3.56	5.81	5.04	3.12, 8.16
Concussion						
No past injury‡	49	55,954.5	0.88			
Past injury	44	29,253.0	1.50	1.72	1.63	1.07, 2.50
Brachial plexus						
No past injury‡	24	53,674.5	0.45			
Past injury	55	30,826.5	1.78	3.99	3.21	1.87, 5.52
Right upper extremity§						
No past injury‡	41	37,369.0	1.10			
Past injury	85	41,158.5	2.07	1.88	1.61	1.07, 2.45
Left upper extremity§						
No past injury‡	46	40,849.0	1.13			
Past injury	74	35,589.0	2.08	1.85	1.70	1.12, 2.57
Thoracic spine/chest						
No past injury‡	26	75,503.0	0.34			
Past injury	21	12,884.5	1.63	4.73	4.26	2.19, 8.28
Lumbar spine/pelvis						
No past injury‡	36	60,520.5	0.60			
Past injury	25	28,871.0	0.87	1.46	1.47	0.88, 2.47
Right lower extremity¶						
No past injury‡	66	24,080.0	2.74			
Past injury	243	56,886.0	4.27	1.56	1.34	1.00, 1.81
Left lower extremity¶						
No past injury‡	56	26,335.0	2.13			
Past injury	225	53,072.5	4.24	1.99	1.53	1.10, 2.12

* No. of injuries per 1,000 athlete exposures.
† Poisson regression model using generalized estimating equations to account for within-subject correlation. Results were controlled/adjusted for year of varsity sport participation.
‡ Reference category.
§ All upper extremity injuries from the shoulder to the hand.
¶ All lower extremity injuries from the hip to the foot.

broken down by body region of injury (2). Specifically studying knee injuries, Powell and Schootman found “a tendency for AstroTurf to be associated with an increased risk for knee sprains and MCL and ACL injuries under very specific conditions” (3, p. 692). Other investigators found higher injury rates among professional football players on natural grass as compared with a synthetic field, although it was not clear from that investigation how athlete exposure data were collected or what type of synthetic surface the athletes played on (24).

One very interesting finding in this investigation concerns the field comparisons presented separately for the University of Calgary team and the other teams combined for the years 1993–1996. Because the University of Calgary team consistently played their home games on AstroTurf while all other team home venues in the Canada West Universities Athletic Association had natural grass, other teams may have had increases in injury rates because of their less frequent exposure to artificial turf (i.e., the change of turf and not the type of turf accounted for the increased injury incidence) (25, 26). This result suggests that artificial surfaces may be safe as long as they are used consistently. However, since our study findings relate only to acute injuries, further research is required to determine the influence of consistent participation on artificial surfaces and gradual-onset injury risk.

There are many arguments both for and against artificial turf (27), and although the evidence from this investigation suggests a higher incidence of injury on artificial turf, further study controlling simultaneously for a number of factors—shoe type, bracing or taping, temperature, history of injury, team, field conditions, athlete position, and whether or not an athlete is a starting player for games played on both artificial turf of various types and natural grass—is warranted.

Games versus practice periods

Injury rates were estimated to be substantially higher for all body regions during games as compared with practice periods. This effect was most pronounced for head and neck injuries, where there was a 10-fold increase in the injury rate during games versus practices. Other investigators have provided evidence for a higher incidence of head and neck (5, 8), knee (6, 24), and overall (2, 9, 28) injuries in competition, although the risk changed depending on the type of injury in some studies (28). Still other investigators have found similar absolute numbers of injuries incurred in games and practices but have maintained that if player exposure (i.e., the amount of time players spend participating in games vs. practices) (7, 10, 29) and amount of contact (12) were accounted for, game injury rates would be much higher. Those studies conveying higher numbers of injuries in practices versus games failed to address the issue of player exposure (11, 30). A likely explanation for the higher game injury rate concerns the increased player-to-player contact in games as compared with practices (18). Cantu and Mueller (8) have also noted that catastrophic football injuries, most often associated with blocking and tackling, were more prevalent during games. It has been suggested that limited player contact in practice periods does not affect win-loss records, at least at the high school level (7).

Wet versus dry field conditions

It is interesting to note the difference in lower extremity injury risk associated with participation on artificial turf versus natural turf under wet and dry field conditions during games. It is possible that the condition of the field modifies the risk associated with field type. This is simply speculation, as the confidence intervals for the lower extremity incidence density ratios for the comparison between artificial turf and natural turf demonstrated substantial overlap and thus might have been the same under both conditions. However, similar results were reported by Adkison et al. (1), where wet Tartan Turf had an estimated higher injury rate than dry Tartan Turf. Field conditions should be accounted for in the comparison of turf type.

Year of varsity sport

Veteran players approaching their fifth year of participation were at increased risk of injury in all body regions in comparison with less experienced players. This effect persisted even when data were controlled for history of injury in the Poisson regression analysis. Other investigators have found similar trends but have suggested that this finding is due to the effects of history of injury (4, 7). However, those studies did not categorize types of injuries into specific body regions. Another study found that experience did not influence the proportion of injuries, although the study was completed among high school athletes and did not account for athlete exposure to participation (11). Jackson et al. (24) found that professional players with less than 2 years of experience were 5.8 times more at risk for knee injuries than players with greater than 2 years of experience. However, this effect was not controlled for previous injury. Factors that could account for the difference between our findings and those of other studies include age, continuing risk-taking behavior, incurred playing time, and the potential cumulative effect of repetitive loading over many years of participation.

History of injury

An almost ubiquitous increase in injury risk was associated with those individuals who had a history of injury to a specific region of the body. Perhaps of most concern was the fivefold elevated risk of injury associated with having experienced a prior neck injury, even after data were controlled for year of varsity sport. A similar though not as dramatic effect was evident for upper extremity, thoracic spine and chest, and lower extremity injuries. Other investigators have observed higher incidence rates for persons who have a history of injury (4, 7, 15). A study on rugby injuries (31) also demonstrated higher injury rates for those with a past injury. This type of information is very useful in preseason screening, because it draws attention to the need to effectively manage those athletes with a prior injury. Specific stretching and/or strengthening intervention programs could be implemented randomly for athletes who have a specific type of previous injury (such as neck injury) to determine whether their injury risk could be lowered.

Limitations of this study

It is evident that a large number of comparisons were made in this analysis. As a result, we must acknowledge the likelihood of type I error (i.e., the probability of false-positive statistical results). However, we chose to present confidence limits in order to provide a plausible range for each effect rather than rely on p values using an arbitrary cutpoint (i.e., $\alpha = 5$ percent) to decide whether these effects were real. The consistency and biologic plausibility of the findings make chance (i.e., spurious associations due to multiple testing) an unlikely explanation for the results.

Using only acute injuries may have changed the effects of many risk factors on the risk of injury. For example, in the comparison of field types, it has been suggested that limiting the analysis to acute injuries might cause one to underestimate any negative effect of artificial turf in producing injuries that occur because of repeated athlete participation on this type of surface (27).

Selection bias is unlikely to have affected these results. Only 2.9 percent of the athletes did not consent to participate in this investigation over the 5-year period (18). The presence of dedicated team athletic therapists and physicians made it unlikely that the athletes would have sustained an injury and sought health care elsewhere, making loss to follow-up a nonissue.

The homogeneity of player ages, skill levels, and other physical characteristics makes confounding by these factors unlikely. Results for history of injury were controlled for year of varsity sport participation and vice versa.

The objective nature of the exposures and the access to athletic therapists and physicians for injury assessment and diagnosis (i.e., outcome), respectively, make information bias an unlikely explanation for the results.

It is possible that those athletes who were more likely to report injuries on the preseason medical form and throughout the season would also be more likely to report subsequent injuries. This cannot be excluded as a possible explanation for the association between past injury and higher subsequent injury risk. However, the associations grew stronger when particular body regions were considered. Our sensitivity analysis also indicated that the underreporting would need to be so extreme as to be untenable to effect a meaningful change in the largest point estimates. It is unlikely, then, that the past injury findings are a consequence of differential injury reporting.

The athletes in this investigation represented "survivors" of all previous years of football in the sense that none had suffered a career-ending injury. This, coupled with the elite level of varsity play and the homogeneous age range, may limit the generalizability of these findings to different age groups and levels of play.

Conclusions

This study was among the first to have captured participation information on individual players in intercollegiate football and on a group of players that were homogeneous in terms of age and skill level. The injury rates derived in this study are therefore more reliable than those from investigations where player exposures were estimated on the basis of overall team participation. We identified several factors that increased injury risk, including having a history of injury, being a veteran approaching the fifth year of play, participating in a game, and playing on an artificial surface, although infrequent use of an artificial surface may explain this relation. This comprehensive study has provided the information necessary to proceed with interventions aimed at reducing the overall incidence of injury in Canadian football.

ACKNOWLEDGMENTS

This study was supported by the Olympic Oval Endowment Fund of the University of Calgary Sport Medicine Centre.

The athletic therapists and physicians who diligently collected data at the involved institutions were instrumental in the completion of this project.

REFERENCES

1. Adkison JW, Requa RK, Garrick JG. Injury rates in high school football: a comparison of synthetic and grass surfaces. Clin Orthop 1974;99:131–6.
2. National Collegiate Athletic Association. Injury Surveillance System. (Report). Indianapolis, IN: National Collegiate Athletic Association, 1993:1–50.
3. Powell JW, Schootman M. A multivariate risk analysis of selected playing surfaces in the National Football League: 1980 to 1989. Am J Sports Med 1992;20:686–94.
4. Kraus JF, Gullen WH. An epidemiologic investigation of predictor variables associated with intramural touch football injuries. Am J Public Health 1969;59:2144–56.
5. Albright JP, McAuley E, Martin RK, et al. Head and neck injuries in college football: an eight-year analysis. Am J Sports Med 1985;13:147–52.
6. Albright JP, Powell JW, Smith W, et al. Medial collateral ligament knee sprains in college football: effectiveness of preventative braces. Am J Sports Med 1994;22:12–18.
7. Blyth CS, Meuller FO. Football injury survey. Part 1. When and where players get hurt. Phys Sportsmed 1974;2:45–51.
8. Cantu RC, Mueller FO. Catastrophic football injuries in the U.S.A.: 1977–1990. Clin J Sport Med 1992;2:180–5.
9. DeLee JC, Farney WC. Incidence of injury in Texas high school football. Am J Sports Med 1992;20:575–80.
10. Olson OC. The Spokane study: high school football injuries. Phys Sportsmed 1979;7:75–82.
11. Powell J. 636,000 injuries annually in high school football. Athletic Training 1987;22:19–22.
12. Prager BI, Fitton WL, Cahill BR, et al. High school football injuries: a prospective study and pitfalls of data collection. Am J Sports Med 1989;17:681–5.
13. Mueller FO, Blyth CS. North Carolina high school football injury study: equipment and prevention. J Sports Med 1974;2: 1–10.
14. Pritchett JW. A statistical study of knee injuries due to football in high-school athletes. J Bone Joint Surg 1982;64-A:240–2.
15. Robey JM, Blyth CS, Mueller FO. Athletic injuries: application of epidemiologic methods. JAMA 1971;217:184–9.
16. Meeuwisse WH, Love EJ. Development, implementation, and validation of the Canadian Intercollegiate Sport Injury Registry. Clin J Sport Med 1998;8:164–77.
17. Meeuwisse WH, Hagel BE, Mohtadi NG, et al. The distribution and determinants of injury in men's Canada West university football. (Abstract). Clin J Sport Med 1999;9:115.
18. Meeuwisse WH, Hagel BE, Mohtadi NG, et al. The distribution of injuries in men's Canada West university football: a 5-year analysis. Am J Sports Med 2000;28:516–23.
19. Meeuwisse W, Love E. Athletic injury reporting: development of universal systems. Sports Med 1997;24:184–203.
20. Liang K-Y, Zeger SL. Longitudinal data analysis using generalized linear models. Biometrika 1986;73:13–22.
21. Stata Corporation. Stata statistical software. College Station, TX: Stata Corporation, 1997.
22. Rothman K, Greenland S. Modern epidemiology. Philadelphia, PA: Lippincott-Raven, 1998.
23. Levy IM, Skovron ML, Agel J. Living with artificial grass: a knowledge update. Part 1: basic science. Am J Sports Med 1990;18:406–12.
24. Jackson RW, Reed SC, Dunbar F. An evaluation of knee injuries in a professional football team—risk factors, type of injuries, and the value of prophylactic knee bracing. Clin J Sport Med 1991;1:1–7.
25. Stanford Research Institute. National Football League 1974 Injury Study. Menlo Park, CA: Stanford Research Institute, 1974.
26. Skovron ML, Levy IM, Agel J. Living with artificial grass: a knowledge update. Part 2: epidemiology. Am J Sports Med 1990;18:510–13.
27. Pine D. Artificial vs natural turf: injury perceptions fan the debate. Phys Sportsmed 1991;19:125–8.

28. Whiteside JA, Fleagle SB, Kalenak A, et al. Manpower loss in football: a 12-year study at the Pennsylvania State University. Phys Sportsmed 1985;13:103–14.
29. Canale ST, Cantler ED, Sisk TD, et al. A chronicle of injuries of an American intercollegiate football team. Am J Sports Med 1981;9:384–9.
30. Brodersen MP, Symanowski JT. Use of a double upright knee orthosis prophylactically to decrease severity of knee injuries in football players. Clin J Sport Med 1993;3:31–5.
31. Bennell K, Wajswelner H, Lew P, et al. Isokinetic strength testing does not predict hamstring injury in Australian rules footballers. Br J Sports Med 1998;32:309–14.